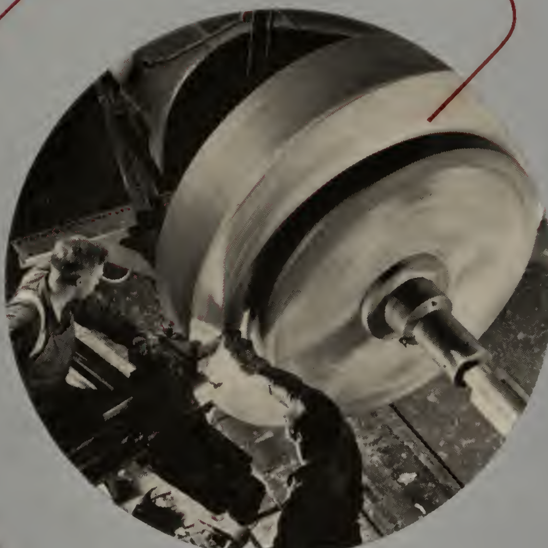


FORMING ALUMINUM

1941

ALUMINUM COMPANY
OF AMERICA
1941

FORMING ALUMINUM

FOREWORD

Aluminum alloys are readily formed by drawing, spinning, embossing and practically every metalworking process. Considerable data on these various fabrication methods are presented in this booklet. The material was prepared by engineers of Aluminum Company of America, and was first published as a series of articles called "The Cold Working of Sheet Aluminum" in American Machinist. Because it presents valuable and timely data, this copyrighted series is reprinted herein with the permission of the publisher.

CONTENTS

Available alloys 5
Index to formability 7
Two groups of alloys 9
Selection of alloy 11

Blanking and piercing 13
Punch and die alignment 14
Sheet and tools oiled 17
Piercing and perforating 18

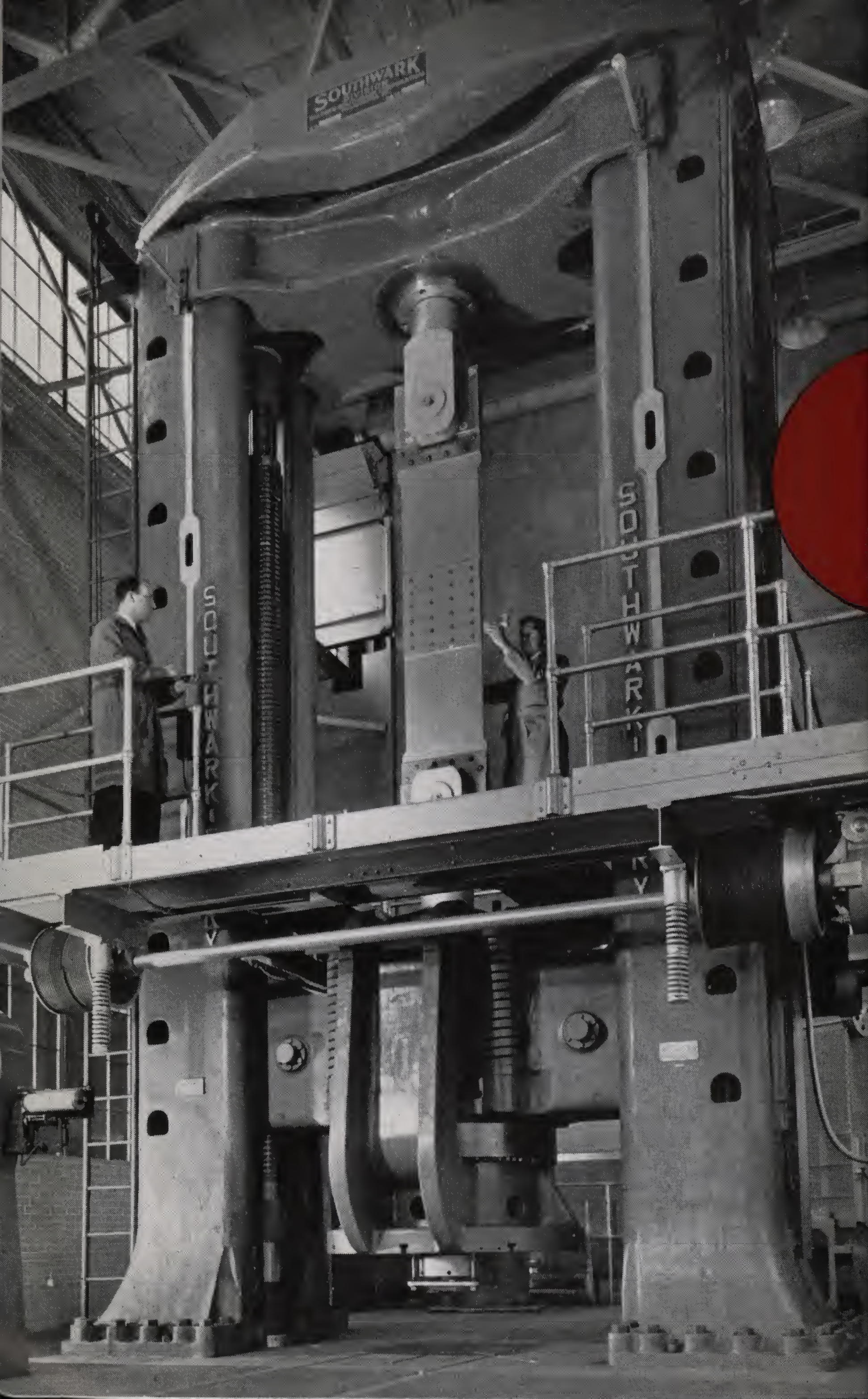
Drawn shapes 21
Design of tools 23
Types of drawn shells 25
Choice of lubricant 28

Spun shapes 31
Lathes and chucks 35

Shape forming 39
Metal spring-back 40
Forming lubricants 45

Embossing, coining and stamping 47
Simple press tools used 51
Effect of material used 53

Sales offices 54


SOUTHWARK
SOUTHWARK
SOUTHWARK

Aluminum is one of the most workable of the common commercial metals. Available in all forms in which metals are produced, it is readily fabricated into a variety of shapes by practically every metalworking process. However, the metalworker should not think of aluminum as just one material, but rather as a series of

AVAILABLE ALLOYS

alloys which come in a wide range of tempers. The characteristics of these alloys affect shop practices, and should be thoroughly understood.

While much is known about these alloys and the metallurgy of aluminum may be called a science, metalworking is more in the nature of an art. Especially is this true in the case of spinning where the "feel" of the spinner is highly important and the spirit of the artisan is much alive.

Whenever aluminum or any other metal is worked cold—whether in making a basic commodity, such as sheet, or in later fabricating operations—strain hardening takes place. During the manipulation of the metal, the tensile and yield strengths are increased and the elongation is lowered. How these mechanical properties vary for the various tempers in the different alloys is shown in Table I, page 8.

Figure 1—Annealed circular blanks being removed from the conveyor of a continuous furnace.

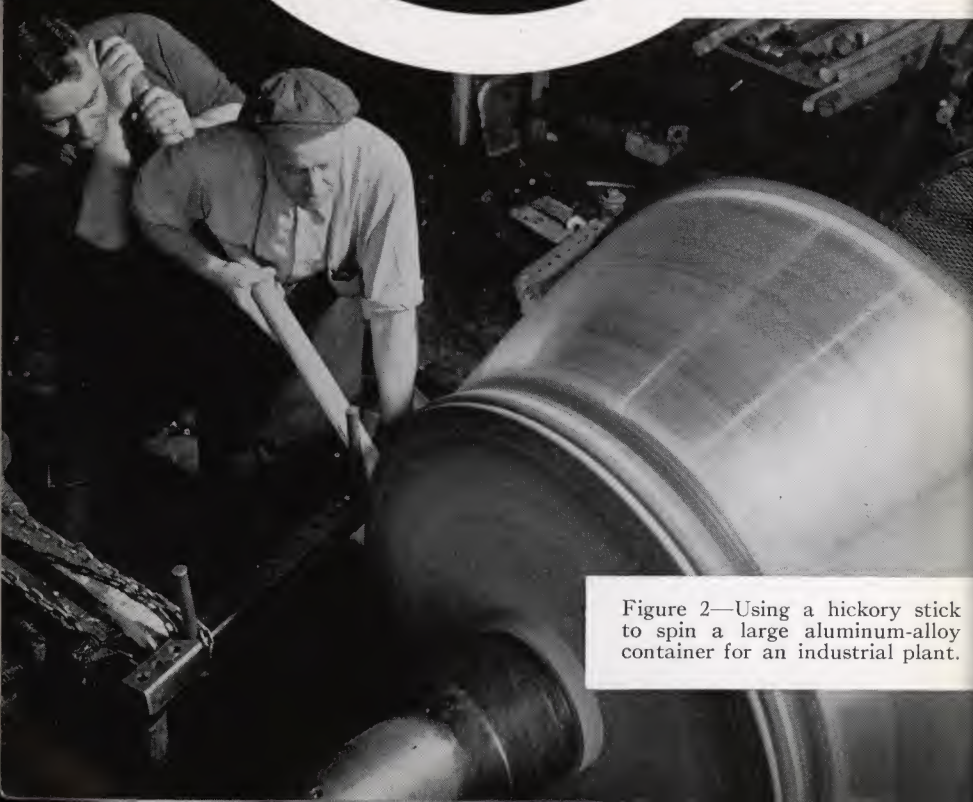


Figure 2—Using a hickory stick to spin a large aluminum-alloy container for an industrial plant.

INDEX TO FORMABILITY

The three properties mentioned serve as an indication, though not as an absolute measure, of the workability or formability of the material. Unlike mild steel, aluminum and other nonferrous alloys do not have a yield point; that is, there is not a stress at which the metal deforms plastically without any increase in the stress. However, after a certain stress has been applied, the metal does cease to deform in direct proportion to the amount of stressing, and if the load is then removed the metal will be found to have taken a permanent set. Increasing the stress increases the permanent deformation.

For purposes of design, the unit stress which produces a permanent set of 0.2 per cent of the original dimensions is defined as the yield strength. If there is a considerable range between yield strength and tensile strength, the metal is usually easier to work than if this range is small. Then, too, if elongation is high, the metal is naturally easier to form.

In choosing the proper temper to use, these properties should all be considered. However, while they are an *index* to formability, the actual ability of the material to be readily worked should be based on its performance on the tools to be used in production. This is the true test which includes all factors.

Commercially pure aluminum, known as 2S,* is particularly noted for the ease with which it can be drawn, spun, stamped and otherwise formed. In fact, starting with a blank in the annealed temper, it may be taken through successive drawing and spinning operations with no need for intermediate annealing.

---

*These designations are those applied to alloys produced by Aluminum Company of America under the Alcoa trademark.

TABLE I

TYPICAL MECHANICAL PROPERTIES OF ALUMINUM ALLOY SHEET

Alloy and temper	Ultimate strength, lb. per sq. in.	Yield strength,* lb. per sq. in.	Elongation, per cent in 2 inches ($\frac{1}{16}$-in. specimen)	Brinell hardness (500-kg., 10-mm. ball)
2S-O	13,000	5,000	35	23
2S-¼H	15,000	13,000	12	28
2S-½H	17,000	14,000	9	32
2S-H	24,000	21,000	5	44
3S-O	16,000	6,000	30	28
3S-¼H	18,000	15,000	10	35
3S-½H	21,000	18,000	8	40
3S-H	29,000	25,000	4	55
52S-O	29,000	14,000	25	45
52S-¼H	34,000	26,000	12	62
52S-½H	37,000	29,000	10	67
52S-H	41,000	36,000	7	85
17S-O	26,000	10,000	20	45
17S-T	62,000	40,000	20	100
17S-RT†	65,000	47,000	13	110
24S-O	26,000	10,000	20	42
24S-T	68,000	45,000	19	105
24S-RT†	70,000	55,000	13	116
53S-O	16,000	7,000	25	26
53S-W	33,000	20,000	22	65
53S-T	39,000	33,000	14	80
61S-O	18,000	8,000	22	30
61S-W	35,000	21,000	22	65
61S-T	45,000	39,000	12	95

*Offset 0.2 per cent.

†Temper resulting from additional cold working after heat treatment.

The alloys of aluminum are less ductile than the pure metal, and they offer a wide range of fabricating qualities in their various tempers. On one hand, an aluminum-manganese alloy (known as 3S) is only slightly less easily formed than pure aluminum. On the other hand, some alloys permit but a minimum of forming in their harder tempers. None of the alloys lends itself to as much forming as pure aluminum, and all of them require more liberal radii.

TWO GROUPS OF ALLOYS

The wrought alloys, from which sheet aluminum is rolled, are of two types. In one, comprising the nonheat-treatable alloys, the harder tempers are produced by strain hardening—that is, by cold working. In another type, known as heat-treatable alloys, the mechanical properties are increased by thermal treatments.

The nonheat-treatable alloys, such as 2S, 3S and 52S, cover a wide range of properties. Since these alloys strain-harden as they are formed, the greater amount of work can be done on them if the softer tempers are used as a starting point. Many drawing operations, however, can be done in the half-hard temper, and the less severe draws may be made in the full-hard temper. The temper is designated as "*O*" for annealed or dead-soft, "*H*" for full-hard, and "¼*H*," "½*H*" and "¾*H*" for intermediate degree of hardness.

While the nonheat-treatable alloys are suitable for a great number of products, structures such as airplanes, bridge floor systems, dragline booms and shovel dippers require the higher strengths of the heat-treatable alloys. Among these alloys are 17S and 24S, which are of the duralumin type, as well as 53S, 61S and others.

The fully heat-treated temper of these alloys is designated by the letter "*T*." An intermediate (as-quenched) temper of some alloys, including 53S and 61S, is known as "*W*."

The most widely used heat-treated aluminum alloy is 17S. Both 17S and 24S, now the principal material used in airplane construction, lend themselves to a considerable amount of forming in the heat-treated temper. The more severe operations in these alloys have to be done in the annealed temper, and the part later heat treated. However, the forming often may be done immediately after the metal has been quenched from the heat-treating temperature, so that the age hardening takes place after the metal has been formed to the desired shape rather than before. This practice makes it unnecessary to heat treat the finished article, which may be difficult to handle. It also eliminates the need for

TABLE II

NOMINAL COMPOSITION OF ALUMINUM ALLOYS

Alloy	Alloying elements, per cent*				
	Cu	Si	Mn	Mg	Cr
2S	....	...	...	...	....
3S	....	...	1.2	...	....
52S	....	...	...	2.5	0.25
17S	4.0	...	0.5	0.5	....
24S	4.5	...	0.6	1.5	....
53S	....	0.7	...	1.3	0.25
61S	0.25	0.6	...	1.0	0.25

*Aluminum and normal impurities constitute remainder.

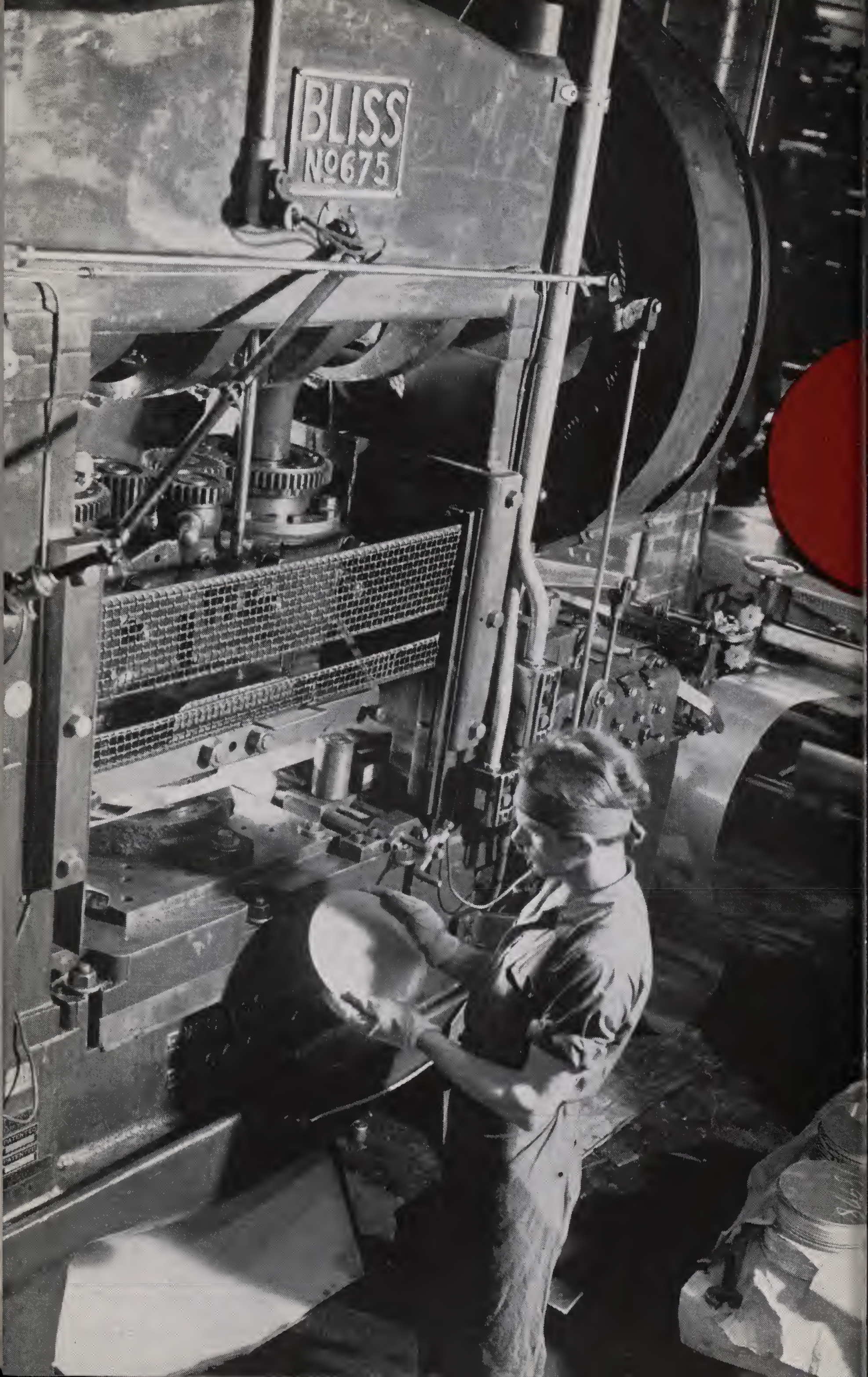
correcting distortion, which usually occurs during heat treating, particularly during quenching.

Alloy 53S is readily formed; and 61S has even better forming characteristics, even though its tensile and yield strengths exceed those of 53S. Alloy 61S can be bent around smaller radii than 53S, and takes more severe deformation. Both these alloys age-harden after forming in the as-quenched temper, and thus develop higher strengths. There is no appreciable distortion or change in dimensions during this aging treatment.

A review of Table I will show that a wide range of tempers in commercially pure aluminum and in the aluminum alloys is available for mild forming operations. For the more severe operations, however, the choice may have to be limited to the dead-soft temper.

SELECTION OF ALLOY

Selection of an alloy depends upon other factors, of course, than just its formability. Some products are exposed to marine atmospheres and will have to be made from an alloy such as 52S or 53S. Others, such as containers for transporting chemicals, must not only resist the corrosive influences of the chemical, but must have adequate strength to withstand handling. In such a case, the choice of alloy is limited both by mechanical and chemical considerations. The choice of temper is then made so that, after fabrication, the finally shaped product will have the necessary strength.


BLISS
No675

In blanking aluminum, as in blanking other metals, the tools consist of a punch and a die, the punch being the moving member attached to the ram of the press and the die being stationary on the bed of the press. The material to be blanked is usually in the form of coils or

BLANKING and PIERCING

flat sheet which is fed over the top of the die by hand or mechanically. The necessary guides may be attached to the bed of the press or may be part of the tool.

During the operation of blanking, the material being blanked is pinched between the outer edge of the punch and the inner edge of the die. While the blank is pushed into the die and the punch is pressed into the material, a true cutting action takes place and continues for about one-third of the thickness of the material being blanked. The cutting action is followed by fracturing the material for the remaining two-thirds of the thickness. Examination of the edges of the blank will show a bright band indicating the depth of actual cutting, and a wider band showing the fracture.

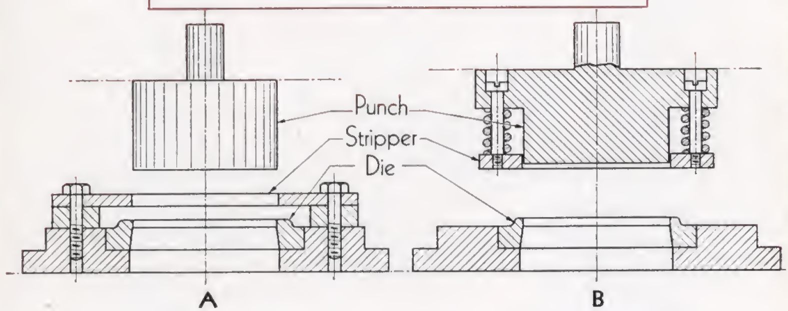
In blanking aluminum, the punch usually is made of annealed tool steel, while the die almost always is made of hardened tool steel. The faces of the punch and die should be ground to insure keen cutting edges. In cases

where it is necessary to reduce the load on the press, it is recommended that the top of the die be ground so that the cutting edge is not on one plane around the die opening. One method is to have two opposite points that are high, with low points between them. This is readily accomplished by tilting the die on opposite angles when grinding the top of the die. The difference between the height of the high and low points should be at least one-half of the thickness, but preferably the full thickness, of the material to be blanked. It should be understood when cutting out blanks which must be flat, that the punch should be ground flat and the die may have high and low points. When punching holes in material that must be kept flat, the die should be ground flat and the punch may have high and low points.

PUNCH AND DIE ALIGNMENT

Many blanking tools in use have no means of aligning the punch and the die. This puts a great responsibility on the die setter, and there is always a chance of shearing

Figure 3—Scrap may be removed from the punch by stationary or spring strippers.



or scoring the punch. Mounting the punch and die in a leader pin die set is recommended since the time needed to set up the tool is shortened considerably and the cost of tool maintenance is reduced.

Table III shows the clearance between the punch and die for blanking various aluminum alloys and tempers. When these clearances are used, the power needed both to operate the tool and to do the stripping of the scrap will be at a minimum. The clearances used in actual practice are about one-half those given in the table, so as to allow for the wear that occurs, especially on the punch diameter.

There are a number of different methods for stripping the scrap from the punch. The two most commonly used are: (1) a stationary stripper, rigidly attached to the die, as shown at *A* in Figure 3; and (2) a spring stripper attached to the punch member, as shown at *B*.

TABLE III

PUNCH AND DIE CLEARANCES FOR BLANKING

(*t=thickness of sheet in inches*)

Aluminum sheet alloy	Clearance		Aluminum sheet alloy	Clearance	
	On a side	On the diameter		On a side	On the diameter
2S-O	0.10t	0.20t	24S-O	0.13t	0.26t
2S-½H	0.12t	0.24t	24S-T	0.16t	0.32t
2S-H	0.14t	0.28t			
			52S-O	0.13t	0.26t
3S-O	0.10t	0.20t	52S-½H	0.14t	0.28t
3S-½H	0.12t	0.24t	52S-H	0.15t	0.30t
3S-H	0.14t	0.28t			
			61S-O	0.11t	0.22t
17S-O	0.13t	0.26t	61S-W	0.12t	0.24t
17S-T	0.16t	0.32t	61S-T	0.14t	0.28t

Figure 4—Aluminum alloy strip sheet being automatically fed into a 300-ton press for blanking.

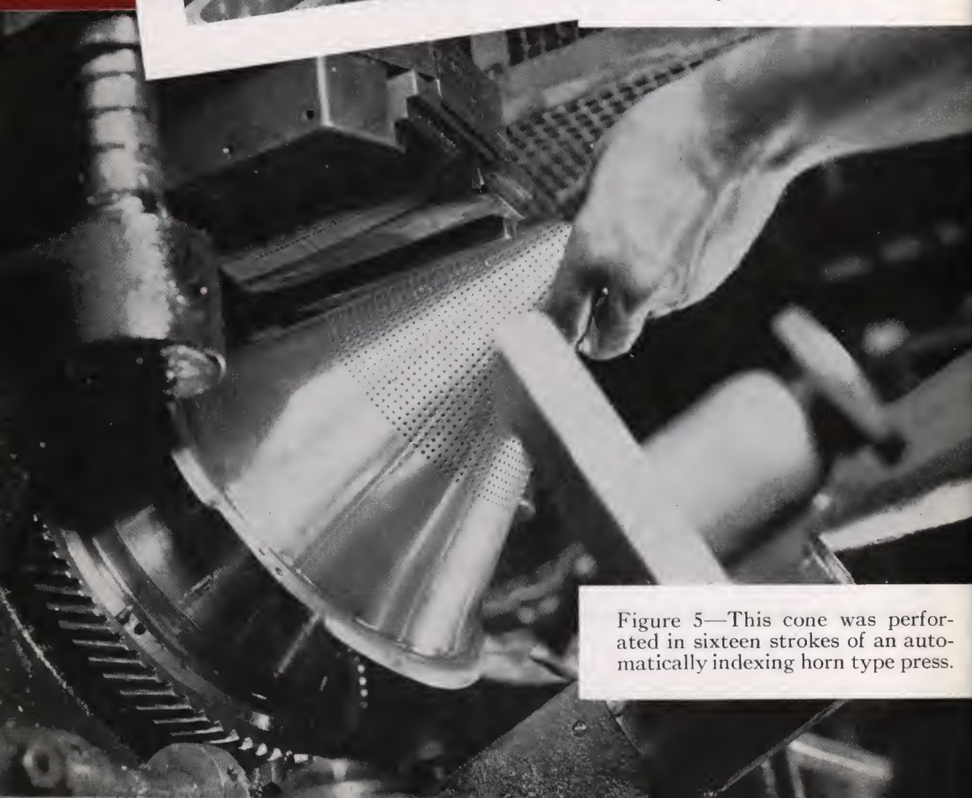


Figure 5—This cone was perforated in sixteen strokes of an automatically indexing horn type press.

Table IV shows the recommended scrap on the sides and between blanks for various gauges and diameters. Standard mill tolerances on widths for coils and flat sheet were taken into consideration when calculating the scrap allowances given in this table.

SHEET AND TOOLS OILED

Lubrication is essential in keeping tool maintenance costs low. A medium grade of engine oil plus a small percentage of fatty oil diluted with kerosene has been found to give the best results when hard aluminum sheet is being blanked. When the sheet is of a softer alloy or

TABLE IV

SCRAP ALLOWANCES FOR BLANKING

Gauge	Blank diameter, inches	Scrap on the side, inches	Scrap between blanks, inches
No. 28 g. (0.013 in.)	0 to 10 incl.	1/8	1/16
to	10 to 20 incl.	3/16	3/32
No. 15 g. (0.057 in.) incl.	20 to 30 and over	1/4	1/8
No. 15 g. (0.057 in.)	0 to 10 incl.	5/32	3/32
to	10 to 20 incl.	7/32	1/8
No. 12 g. (0.081 in.) incl.	20 to 30 and over	5/16	5/32
No. 12 g. (0.081 in.)	0 to 10 incl.	3/16	1/8
to	10 to 20 incl.	1/4	5/32
No. 8 g. (0.128 in.) incl.	20 to 30 and over	3/8	3/16

temper, the engine oil and fatty oil mixture is used without dilution. It is desirable to lubricate both the sheet to be blanked and the cutting edges of the tool. By pulling the sheet being blanked between felt pads saturated with the lubricant, a thin film of lubricant will be applied to the surface of the sheet. The felt pads are usually attached directly to the die or on the bed of the press so that the lubricating will be done just before the metal reaches the die. A ring of felt placed around the punch above the stationary or spring stripper may be used for more direct lubrication of the punch. The felt is saturated with lubricant which trickles down to the edge of the punch.

When blanking bright-finished aluminum sheet where it is necessary to maintain the bright finish, it is recommended that the punch and die face be covered entirely with cloth except at the cutting edges. The stripper usually is covered with cloth to avoid scratches while the metal is being stripped from the punch. A common method of holding the cloth on the various parts of the tool is to use shellac as an adhesive.

PIERCING AND PERFORATING

Piercing is fundamentally the same as blanking, and consists of cutting small holes, such as rivet holes, by means of press tools. The term "blanking" is used if the holes are large, or if the part cut out of the hole is the usable portion and the remaining metal, the skeleton scrap. Perforating is the term applied to the piercing of many closely spaced holes.

A difficulty commonly experienced when piercing or

perforating aluminum is the lifting of the slugs when the punch is moved out of the die on the return stroke of the press. To avoid this difficulty, the clearance between punch and die should be not more than five per cent of the metal thickness.

Piercing and perforating commonly are done in single-action presses. In making holes in the side-walls of hollow ware, however, a horn press is used.

Figure 6—Piercing holes in a rectangular aluminum container in a 50-ton single-action horn type press.

In a draw press the punch operates like that in a blanking press, but the stroke must necessarily be greater. Small pieces may be drawn in single-action presses, in which the blankholder is raised or lowered by spring or

DRAWN SHAPES

pneumatic pressure. For quantity production and for larger pieces, however, drawing is done in double-action presses, in which mechanical linkage or cams operate the blankholder.

The size and capacity of a drawing press depend upon such factors as the diameter and thickness of blank, shape of drawn item, and alloy and temper of the sheet being used. In Table V are given the capacities of presses used for drawing various sizes of aluminum-alloy blanks.

There are five aluminum alloys that generally are suitable for producing drawn shapes. These are designated by Aluminum Company of America as 2S, 3S, 52S, 53S and 61S. The first three are generally called nonheat-treatable alloys, while 53S and 61S are heat-treatable alloys.

When drawing nonheat-treatable alloy sheet, the severity of the draw determines the temper to use. Annealed sheet is used for severe draws, while half-hard or even full-hard sheet may be satisfactory for the less severe draws.

TABLE V

CAPACITY OF PRESSES USED FOR DRAWING VARIOUS BLANKS

Type of Press	Capacity, tons	Maximum diameter of shell, inches	Maximum thickness of blanks, inches	Maximum depth of draw, inches
Double-action toggle	63	8⅞	0.051	4¾
Double-action toggle	125	14	0.102	8½
Double-action toggle	148	15½	0.102	9½
Double-action toggle	282	23	0.125	10
Double-action toggle	300	27	0.125	10
Double-action toggle	360	25	0.125	14½
Double-action toggle	400	30	0.156	12
Double-action toggle	550	30	0.187	17
Double-action toggle	500	37	0.250	14
Hydraulic	1300	49	0.3125	24

TABLE VI

EFFECT OF DRAWING ON MECHANICAL PROPERTIES

Alloy	No. of draws	Thickness, inches	Tensile strength, lb. per sq. in.	Increase, per cent	Yield strength, lb. per sq. in.	Elongation, per cent in 2 inches	Approximate hardness
3S	0	0.103	16,000	....	6,000	30.0	0
	1	0.100	18,740	17.2	16,700	11.0	¼H
	2	0.097	22,140	38.4	20,800	9.0	½-¾H
	3	0.097	23,710	48.2	21,900	8.0	¾H
	4	0.098	24,240	51.5	22,300	7.5	¾H
52S	0	0.103	29,150	....	14,200	27.0	0
	1	0.101	34,390	18.0	31,600	6.0	¼-½H
	2	0.090	39,710	36.2	37,100	5.0	¾H
	3	0.087	42,680	46.5	38,600	5.5	H
	4	0.089	43,750	50.2	36,100	6.0	H

Alloy 53S sheet is generally drawn from the annealed (*O*) or the quenched (*W*) temper, and the shell later brought to the fully heat-treated temper. Shells drawn from sheet in the quenched (*W*) temper require aging at 320°F. or slightly higher, the time of heating varying with the temperature chosen. When sheet in the soft temper is used, the shell must be heat treated at 960°F. and then aged. The *W* temper is used wherever possible so as to eliminate the need for heat treating the drawn shells, which may be difficult to handle and which distort during quenching. In most cases, the distortion from heat treatment requires corrective operations.

DESIGN OF TOOLS

The tools used in drawing aluminum may be divided into four parts: die, knockout, blankholder and punch. While these are similar to those used for other metals, the designer should take into account differences in amount of reduction per draw, radii on the tools and change in metal thickness.

During drawing the metal strain-hardens and changes from the annealed to the harder tempers, with an increase in mechanical properties, as shown in Table VI. It therefore becomes less workable, and the reductions per draw in successive draws must be decreased. For deep-drawn cylindrical shells in alloys 2S-O and 3S-O, the reductions in diameter per draw should be as shown in Table VII.

Since after the third draw there is little change in hardness, the 15-per cent value given in Table VII is suitable for the fourth and all later draws. While the values given in this table may be varied, they should

not be exceeded appreciably. In fact, for harder alloys, such as 52S, in which the increase in strength is greater, the values given in the table may have to be reduced by as much as ten per cent for the first draw and five per cent for succeeding draws.

The radius on the die should be no less than four times and no more than fifteen times the original thickness of the metal. That on the punch should be held to a minimum of four times the thickness. If the radius is too sharp, the resistance to the flow of metal may cause fractures. If the radius is too large, wrinkling may occur in the side-wall of the shell.

The drawing tools should be so designed that the original thickness of the sheet is changed very little. This practice differs from that for brass and steel sheet, which may be reduced in thickness as much as 50 per cent. It is therefore often necessary to redesign tools used for brass and steel when they are to be used in drawing aluminum alloys.

Drawing tools are made from cast iron, high-grade alloy steel or carbon steel, depending on such factors as the type of draw, the alloy sheet to be formed, the final finish desired and the quantity to be made.

TABLE VII

REDUCTION IN DIAMETER FOR DEEP SHELLS

Operation	Desired reduction, per cent	Permissible reduction, per cent
Blank (D)		
First draw (D_1)	40 (or less) D	42D
Second draw (D_2)	$20D_1$	$25D_1$
Third draw (D_3)	$15D_2$	$18D_2$
Fourth draw (D_4)	$15D_3$	$15D_3$

Cast-iron tools have been widely used for a small number of pieces where it is necessary to keep tool costs at a minimum. The saving in this case is obtained both in the cost of the material and in the cost of machining. Cast-iron tools also are well adapted for larger quantities when the requirements for surface finish on the drawn parts are not exacting. However, the presence of scratches and surface imperfections resulting from their use increases finishing costs if a highly polished surface is desired. While somewhat higher in cost, a number of grades of alloy cast iron are sometimes used because they give better results.

On large production runs where the extra cost is justified, high-grade alloy tool steels have been found to give best results. They also are used for drawing shells from hard alloys and on work where scratches must be kept at a minimum. Oil hardening steels usually are used so that the maximum hardness with minimum distortion is obtained during heat treatment.

Intermediate in cost and performance between cast iron and high-grade alloy steels are regular carbon steels with 0.6 to 1.10 per cent carbon.

TYPES OF DRAWN SHELLS

Drawn shells usually are rectangular, cylindrical or hemispherical, although odd shapes are not uncommon. In a rectangular shape, as shown in Figure 8 (circle), the greatest flow of metal occurs at the corners. This flow must be controlled to prevent wrinkles and fractures. Provision for this factor can be made by varying the draw radius. The dimensions of the original blank must be such that there is enough metal to obtain the desired

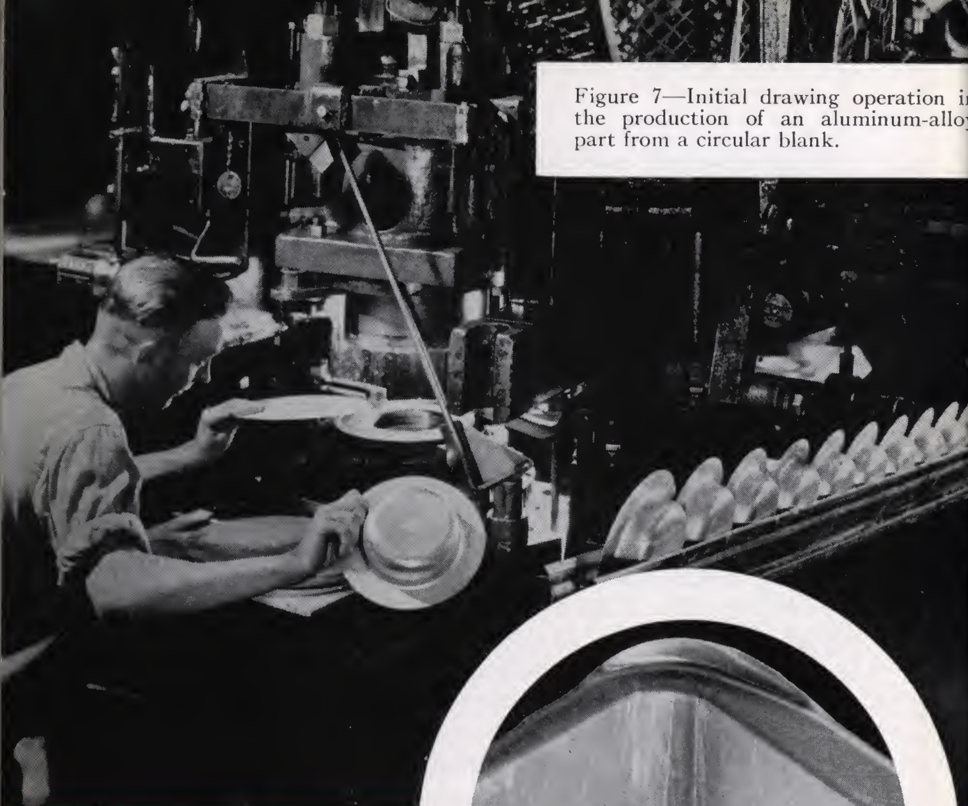


Figure 7—Initial drawing operation in the production of an aluminum-alloy part from a circular blank.

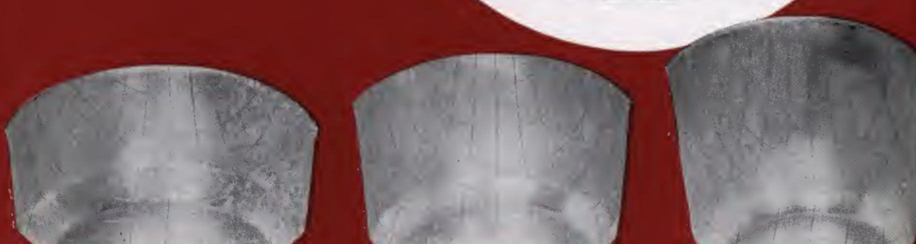


Figure 8—Flow of metal in these drawn shells is indicated by lines scribed on the blanks.

shell. The shape of the blank naturally depends on the shape of the item drawn. Figure 9, page 29, shows typical first and second operation shells and the blank for a rectangular shell. The die dimensions for the various draws are given in Table VIII.

The flow of metal in a drawn cylindrical shape is illustrated in Figure 8 (bottom). Notice that although the shape of the original squares has been changed considerably, their area is about the same, indicating there has been very little change in thickness. Figure 10 (right) shows the sequence of drawing operations, and Table IX gives the die dimensions.

Metal drawn into the form of a dome or a hemisphere has a tendency to wrinkle, especially in the thinner gauges. If such a shape is to be made in one draw, the ratio of the inside diameter of the drawn shell to the

TABLE VIII

DIE DIMENSIONS FOR DRAWING RECTANGULAR SHAPES

First draw......	Add 2.2 times blank thickness to punch dimension
Second draw....	Add 2.2 times blank thickness to punch dimension
Final draw.....	Add 2.0 times blank thickness to punch dimension

TABLE IX

DIE DIMENSIONS FOR DRAWING CYLINDRICAL SHAPES

First draw.................	Punch diameter plus 2.2 times thickness of blank
Second draw...............	Punch diameter plus 2.3 times thickness of blank
Third and succeeding draws..	Punch diameter plus 2.4 times thickness of blank
Final draw of tapered shells..	Punch diameter plus 2.0 times thickness of blank

original metal thickness should be kept below 200; otherwise wrinkles will usually form. If two draws are used to form the shell, it is important that the first shell have sufficient metal at the proper positions so that the second shell will draw without fracturing or wrinkling. The drawing operations are illustrated in Figure 10 (left).

CHOICE OF LUBRICANT

A lubricant for drawing work has two important functions. In the first place it allows the blank to slip readily between the blankholder and the die. Also, it prevents scratching and galling while this movement takes place. Mineral oils or compounded mineral oils are most often used. Water-soluble drawing compounds have been tried, but found unsatisfactory. Some of the oils that have proved suitable in production operations are the following:

Light draws	Light lubricating oil
Medium draws	Mixture of light and heavy lubricating oil
Severe draws	Heavy lubricating oil or 50 per cent mutton tallow and 50 per cent paraffin mixtures
Very severe draws	30 per cent mutton tallow and 70 per cent paraffin mixtures

It should be remembered that proper choice of lubricant for a particular plant is a matter of experience and depends on the tool design, tool material and sheet thickness. Cast-iron and low-carbon-steel tools require a heavier lubricant to prevent scratching than do hardened steel tools. The greater the reduction per draw and the sharper the radii, the heavier must be the lubricant to allow the blank to slip readily into the die. Thick sheet requires a heavier lubricant than thin sheet. It is general practice to use mutton tallow and paraffin when drawing thick sheet.

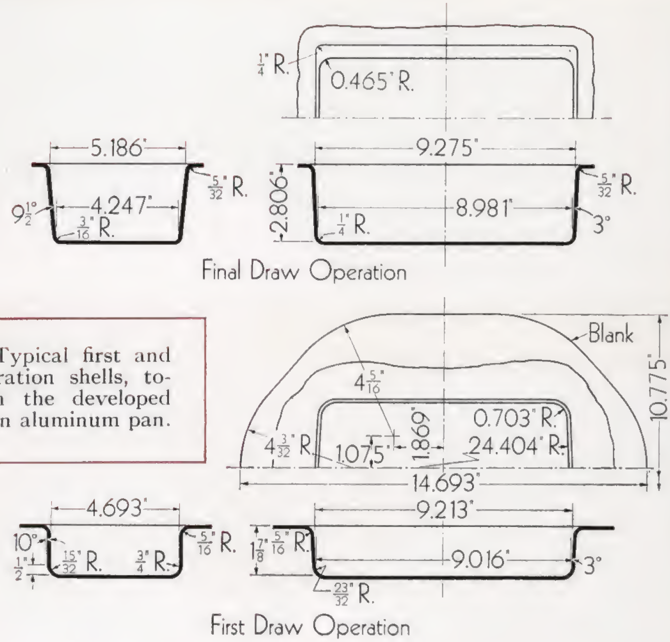


Figure 9—Typical first and second operation shells, together with the developed blank, for an aluminum pan.

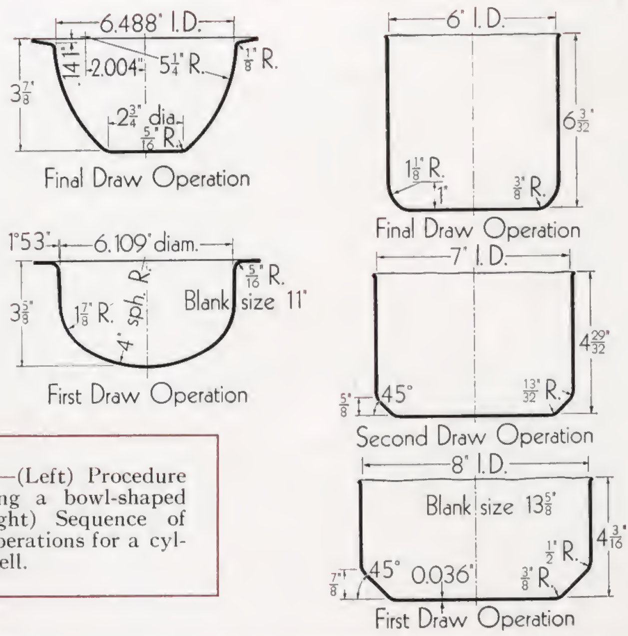


Figure 10—(Left) Procedure for drawing a bowl-shaped shell. (Right) Sequence of drawing operations for a cylindrical shell.

Spinning is one of the oldest metalworking arts, and has been used in making circular hollow ware for many years. While largely replaced by drawing for large-scale production, it is still widely used when tool costs must be kept low, as well as in the manufacture of products which cannot be drawn because of their size or design.

SPUN SHAPES

Since the metal is formed over a chuck rotating in a lathe, the process is limited to symmetrical articles that are circular in cross sections normal to the axis of rotation. Typical spun items are cooking utensils, lighting reflectors, processing kettles and ornaments of many different types.

With an experienced operator, spun articles can be held to reasonably close dimensional accuracy, and will be uniform in size and appearance. However, spinning is truly an art, and the skilled craftsman can spin complicated shapes that the ordinary mechanic would find impossible to produce.

Most spun products are made from a nonheat-treatable alloy of aluminum or commercially pure aluminum (2S), which is more easily spun than any of the aluminum alloys. An aluminum-manganese alloy (3S) is often used because it has greater strength than pure aluminum. Unlike 2S, it requires intermediate annealing on deep

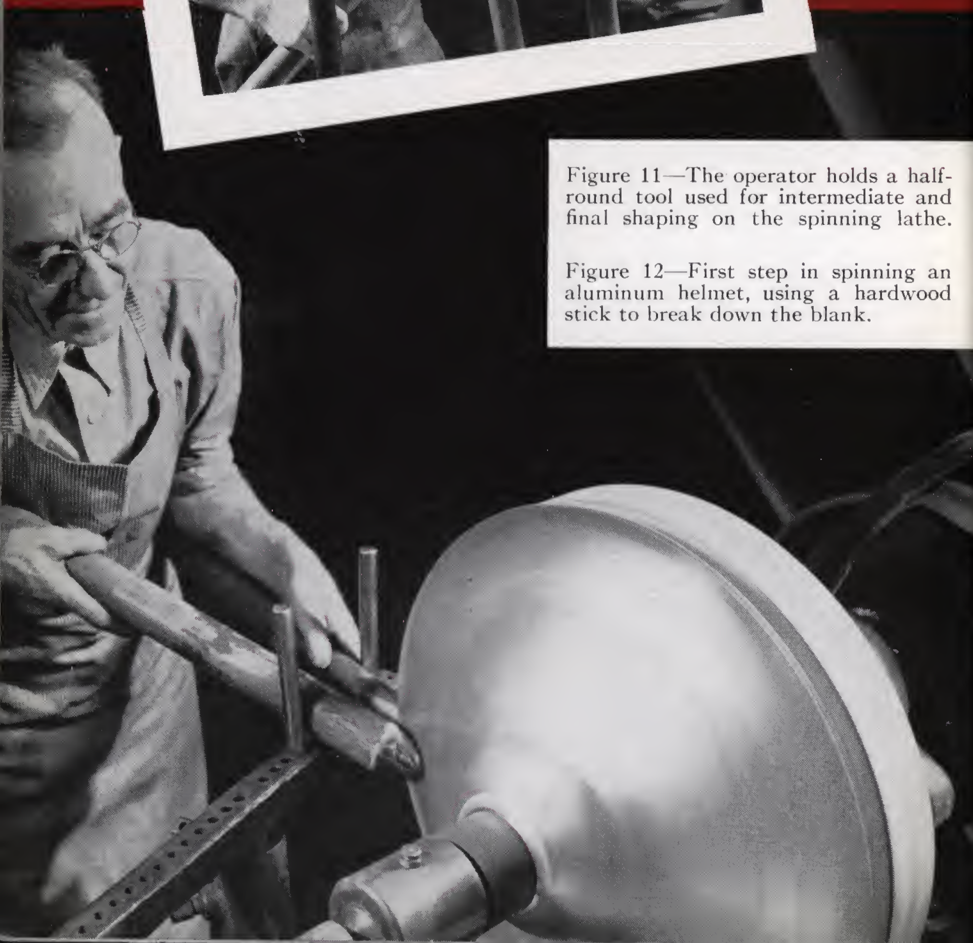


Figure 11—The operator holds a half-round tool used for intermediate and final shaping on the spinning lathe.

Figure 12—First step in spinning an aluminum helmet, using a hardwood stick to break down the blank.

spinning, as well as more breakdown operations. Occasionally, 52S and the heat-treated alloys are spun, but may have to be annealed more often because of their greater rate of strain hardening.

In choosing a blank size, it should be remembered that the finished article is always somewhat thinner than the circular blank, even with the most careful spinning. Allowance should therefore be made for this reduction when selecting the thickness of metal to be used. By using several breakdown operations, however, the thinning can be minimized.

The area of the starting blank should be equal to the surface area of the finished product. Since the blank decreases in thickness during spinning, and therefore increases in area, this will allow for the necessary trimming.

In the spinning operation the circular blank is placed in a suitable lathe and held by pressure against a chuck which has the exact form of the interior of the desired object. The lathe, chuck and blank rotate at a high speed. A hardwood stick or wedge is used to break down the blank, and a "half-round" forming tool (usually made of a steel rod) is used to lay the metal down on the rotating chuck. Typical hand tools used by the operator are shown in Figure 11.

The lathe speed is determined by the thickness and diameter of the blank as shown in Table X. Generally, the lathe should have at least three speeds, such as approximately 1,200, 700 and 250 r.p.m. The lower speed applies to large items and thick sheet. Each operator will have his preferences as to proper speeds; those given in the table simply serve as a guide.

The spinner should observe certain precautions. For example, it is imperative that a flange be maintained on the outside of the "spinning" at all times, even up to the final trimming operation. If wrinkles appear in this flange, the "spinning" should be taken from the chuck,

and the flange hammered smooth. Wrinkles should be removed as soon as they are noticed since they cannot be spun out.

While spinning, the operator is able to feel the metal "flow" beneath the tool. If the metal becomes too hard to "flow" properly, the workability can be improved by heating with a torch while the shell is rotating in the lathe. However, the metal cannot be fully annealed by this method. If it is necessary to fully anneal, the metal should be heated to a temperature of 650°F. to 750°F. The work should be removed from the chuck to carry out this operation successfully. When the proper temperature has been reached, a pine stick rubbed on the metal leaves a charred mark. Annealing with a torch is especially adapted to larger items. In all cases, however, a fast method of heating should be used so as to prevent grain growth. Immersion in molten nitrate bath at 650°F. to 750°F. is satisfactory for small articles. The time of heating varies from 30 seconds to several minutes, depending on the metal thickness.

The number of spinning chucks (or the number of

TABLE X

SPEEDS FOR SPINNING ALUMINUM ALLOYS*

Blank diameter, inches	Thickness of metal	Temperature of metal, deg. F.	Lathe speed, r.p.m.
36 to 72	3/16" to 3/8"	400 max.	50 to 250
24 to 36	12 gauge to 3/16"	Room	250 to 550
12 to 24	20 to 12 gauge	Room	400 to 700
Up to 12	20 to 16 gauge	Room	600 to 1,100

*Lathe speed is affected by the weight and condition of chucks. Generally, the greater the speed, the easier it is to spin aluminum alloys.

reductions) depends on the shape of the finished product, as well as its diameter compared with that of the blank. In general, shells with perpendicular sides require more chucks than those with sloping sides.

After the breakdown operations are all completed, a "final spin" is made to lay the shell tightly against the chuck, starting at the tailstock end of the lathe and working outward. As he proceeds, the operator should make sure the metal is not loose at any point. When the metal is not tight against the chuck, it makes a hollow sound when tapped with a wooden mallet. It is almost impossible to lay a loose intermediate section to the chuck if there is a tight fit at both ends.

After spinning, hemispherical shells will have a flat bottom equal in diameter to that of the back-up block. This flat area can be hammered out to whatever radius or shape is required.

LATHES AND CHUCKS

There are certain differences between spinning lathes and those used for woodworking. The headstock bearing should be larger and should be fitted with a more efficient thrust bearing because of heavier pressures. Lathe size depends, of course, upon the size of blanks used and depth of shells spun. A coarse pitch on the tailstock screw helps in removing the completed product.

Chucks may be made of aluminum alloy, steel, cast iron or hardwood, depending on the quantity and quality of the work. Hardened steel chucks with a high polish produce smooth surfaces and are most economical for products that are buffed or given a similar finish. Imper-

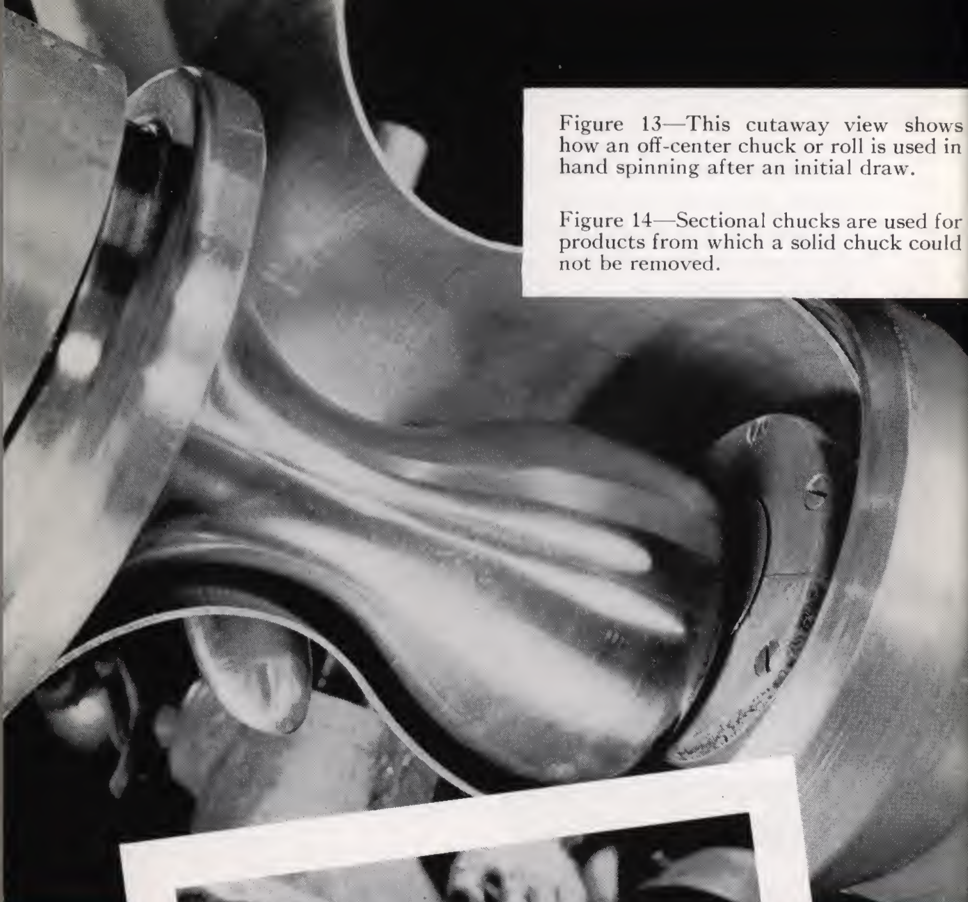


Figure 13—This cutaway view shows how an off-center chuck or roll is used in hand spinning after an initial draw.

Figure 14—Sectional chucks are used for products from which a solid chuck could not be removed.

fections in wood or cast-iron chucks show on the inside finish. This is caused by the high pressures used. Wood chucks may be cheaply built with laminations so that the contour is readily changed. Large items are generally spun over inexpensive wood chucks.

Chucks can be built in one piece unless they are partially enclosed by the shell. In such a case the chuck may be made in sections, as shown in Figure 14. The sections should fit perfectly or an offset at the joint will be impressed on the "spinning." An off-center chuck, Figure 13, which comes in contact with the work only at the point of spinning, also may be used. This off-center chuck (or roll) does not have to be assembled and disassembled and therefore saves time. However, spinning cannot be done near the bottom, and the spun product must have an opening large enough for removal of the entire chuck. If an off-center chuck is used, the bottom of drawn shells may first be formed by means of a bulging operation.

"Spinning on air" is a higher branch of the art in which no chucks are used. The inside of the shell is supported only by a hardwood wedge held by the operator.

The hand-spinner generally uses a hickory stick for breaking down the circular blanks. A forged steel forming tool is used to lay the metal on the chuck. While forming tools vary with the operator and the spun item, a ¾-inch diameter rod with one flat side and one round side is suitable for most products. Special tools are needed for trimming and beading. Spinning tools may be mechanically supported when large shells or thick metal is spun. Page 30 shows a spinning lathe which will take 88-inch diameter blanks and has a power-operated tool holder.

Ordinary laundry soap is the most practical lubricant, especially for larger items, and is applied to the blanks before and while spinning.

Shape forming comprises that class of work which falls within the widely separated fields of embossing and drawing. Forming tools are invariably designed for, but not restricted to, single-action presses. The tool will change a blank of suitable dimensions into a shape conforming to the clearance between the forming punch and the forming die without noticeable alteration of its thickness, width and total length. This is illustrated in Figure 15. The total length, as measured along the neutral axis of the base, sides and radii of the shaped piece, will be found to equal the original length of the piece from which it was formed.

SHAPE FORMING

The design of the forming tool is governed by the shape of the article to be produced, the severity of the form and the anticipated quantity production. In building the tool it is important to select the proper metals that are to come in contact with the aluminum at points where pressure is to be exerted. If the number of pieces to be produced on a tool is small, satisfactory results can be obtained by making the forming parts of the tool from machine steel or castings of a metal or alloy hard enough to stand up under the pressure involved.

Tools for high-production runs should be built to withstand wear and to maintain uniformity. They

should be constructed of a good grade of tool steel which should be hardened to obtain maximum wear resistance. It is important that forming tools be given a high polish so as to remove all tool, grinding and file marks from surfaces over which the metal is to be formed. This is necessary to avoid scratching the metal when it moves into the tool under high pressure.

In tools where the metal is formed into the lower die, it is essential to provide means of removing the part after the forming operation. This can be done by means of an ejector or knockout, either mechanical or hand-operated. The knockout should cover as large an area as possible to lessen the possibility of marking or distorting the metal. The construction of a single-action tool with a spring-actuated knockout is shown in Figure 16.

Forming is a relatively high-speed operation. The outgrowth of this has been the introduction of various types of mechanical feeds which have given excellent economy. With their introduction a series of operations began to be combined. In the forming of aluminum, which rarely needs annealing, this has proved to be a sound practice. The mechanical feed is efficient, as well as a more effective safeguard than the safety devices usually employed with manually fed tools.

METAL SPRING-BACK

The problem of metal spring-back is often encountered in forming operations. When using a dead-soft metal with a low elastic limit, the spring-back is negligible, assuming that the tools are of the proper fit and are properly set up in the press. However, with harder metals and alloys which have a high yield strength, there is considerable metal spring-back which must be com-

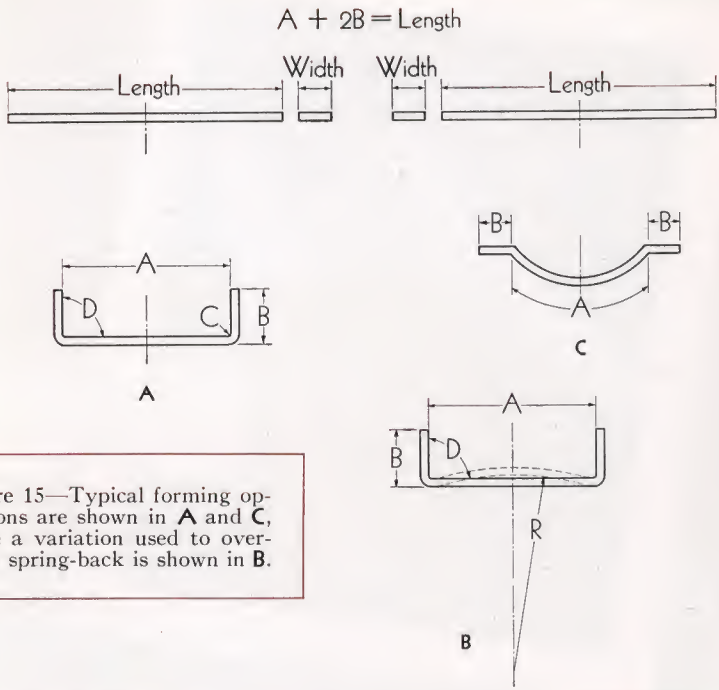


Figure 15—Typical forming operations are shown in **A** and **C**, while a variation used to overcome spring-back is shown in **B**.

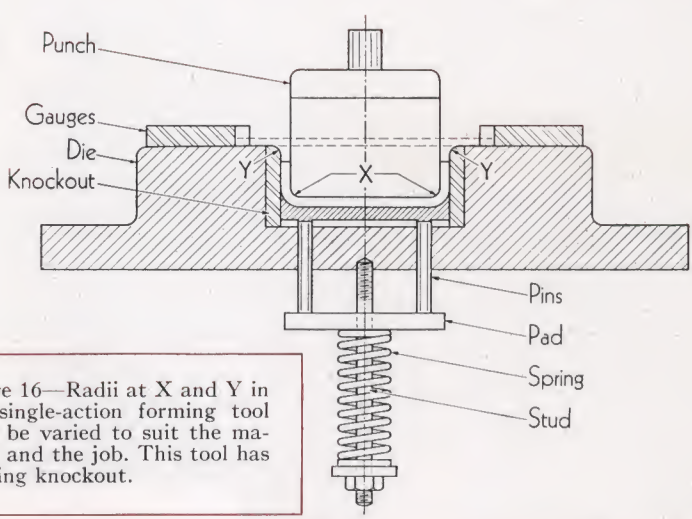


Figure 16—Radii at X and Y in this single-action forming tool must be varied to suit the material and the job. This tool has a spring knockout.

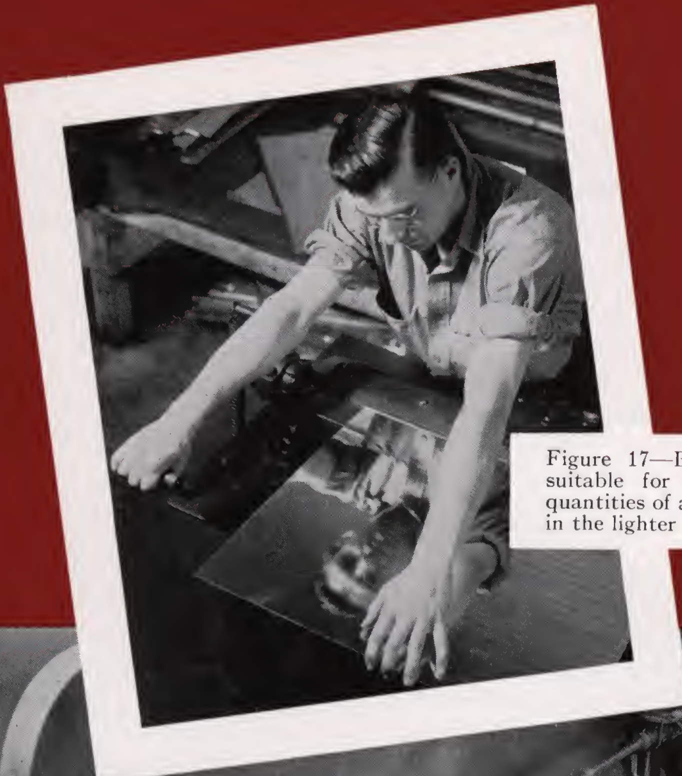


Figure 17—Bar folders are suitable for forming small quantities of aluminum sheet in the lighter gauges.

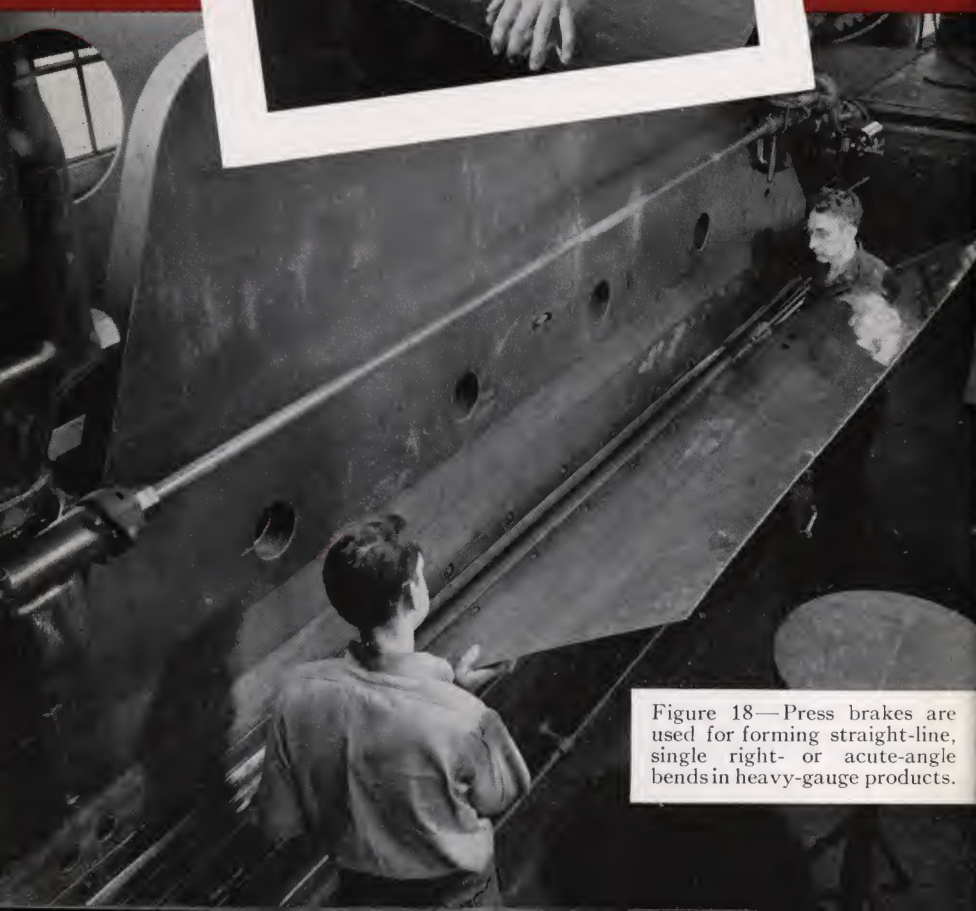


Figure 18—Press brakes are used for forming straight-line, single right- or acute-angle bends in heavy-gauge products.

pensated for in the forming tool. As an illustration, let us consider a piece of metal to be formed as shown in Figure 15A. The bottom must be flat, and the legs must be 90 degrees to the bottom as at *D*. The metal to be used is rather hard, such as 3S-½H aluminum sheet. After the part is formed, measurements might show the legs to be at an angle of 95 degrees with the bottom instead of the desired 90 degrees. If it appears that the tool is hitting or ironing as hard as practical, without distorting the metal or overloading the press, then it is necessary to make a reduction of the radius of the punch at *X*, in Figure 16, until the sides come to the desired 90 degrees. By this means, a permanent set is produced in the metal which does not allow it to spring back.

In some instances the foregoing procedure may not give the desired result. It then becomes necessary to devise a means whereby the angles at *D* must be overbent in order to counterbalance the flare of the legs *B*. Perhaps the simplest and most effective method of doing this is by arching the base during the forming operation, as indicated by the dotted lines of Figure 15B.

When the tool is closed, the part is bowed in the middle as the bends at the sides are set. After removing the part from the tool, the bow in the middle springs out and in doing so draws the legs into parallelism. Naturally, the radius *R* cannot be accurately predicted, but must be determined by cut-and-try development.

Through practical trials the radii for specific bends, using different alloys and tempers, have been compiled and are given in Tables XI and XII. Deviation from these tables may be necessary in cases where a number of bends are made close to each other or are greater than 90 degrees. Table XII refers to the radius *C* in Figure 15A. The minimum permissible radius varies with the nature of the forming operation, the type of forming equipment, and the design and condition of tools. The

minimum working radius for a given material, or the hardest alloy and temper for a given radius, can be ascertained only by actual trial under contemplated conditions of fabrication.

When the requirements as regards tool marking in the formed part are exacting, a large radius on the edge of the die, as indicated by *Y* in Figure 16, is required. However, for practical use, a radius equal to four times the metal thickness will usually be found best.

TABLE XI

ALLOY CLASSIFICATION FOR BENDING

Alloy and temper	Bend classification*	Alloy and temper	Bend classification*
2S-O	A	24S-O†	B
2S-¼H	B	24S-T† ‡	J
2S-½H	B	24S-RT†	K
2S-¾H	D		
2S-H	F	61S-O	B
		61S-W	E
3S-O	A	61S-T	F
3S-¼H	B		
3S-½H	C	52S-O	A
3S-¾H	E	52S-¼H	C
3S-H	G	52S-½H	D
		52S-¾H	F
17S-O†	B	52S-H	G
17S-T† ‡	H		
17S-RT†	J	53S-O	A
		53S-W	F
A17S-O	B	53S-T	G
A17S-T	F		

*For corresponding bend radii see Table XII.

†Alclad 17S and Alclad 24S can be bent over slightly smaller radii than the corresponding tempers of the uncoated alloy.

‡Immediately after quenching, these alloys can be formed over appreciably smaller radii.

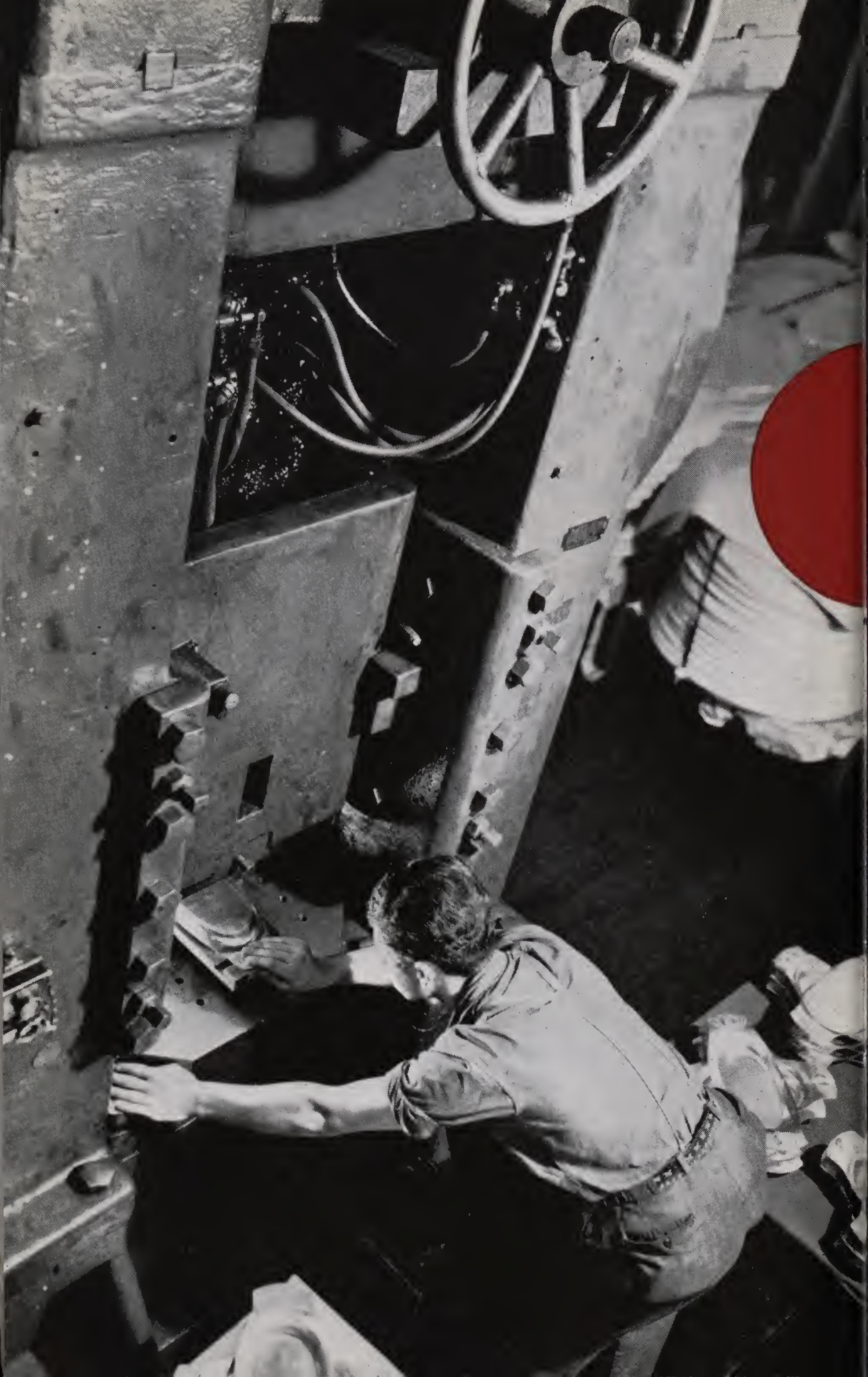
TABLE XII

RADII REQUIRED FOR 90-DEG. BEND IN TERMS OF THICKNESS

		Approximate thickness (t)					
B. & S. Gauge		26	20	14	8	5	2
Dec. Inch		0.016	0.032	0.064	0.128	0.182	0.258
Frac. Inch		1/64	1/32	1/16	1/8	3/16	1/4
Bend Classifications	A	0	0	0	0	0	0
	B	0	0	0	0	0-1t	0-1t
	C	0	0	0	0-1t	0-1t	½t-1½t
	D	0	0	0-1t	½t-1½t	1t-2t	1½t-3t
	E	0-1t	0-1t	½t-1½t	1t-2t	1½t-3t	2t-4t
	F	0-1t	½t-1½t	1t-2t	1½t-3t	2t-4t	2t-4t
	G	½t-1½t	1t-2t	1½t-3t	2t-4t	3t-5t	4t-6t
	H	1t-2t	1½t-3t	2t-4t	3t-5t	4t-6t	4t-6t
	J	1½t-3t	2t-4t	3t-5t	4t-6t	4t-6t	5t-7t
	K	2t-4t	3t-5t	3t-5t	4t-6t	5t-7t	6t-10t

FORMING LUBRICANTS

In forming aluminum parts in press tools, it is advantageous to use a lubricant on the female die side, which is subjected to the sliding or frictional action of the operation. For average forming operations, satisfactory results are obtained by using a medium grade engine oil diluted to the proper consistency with kerosene. For shaping heavy-gauge aluminum or for the more severe forming, a coating of tallow serves as an excellent protective and lubricating agent.



Embossing, coining and stamping are closely associated with the fine arts. They had their origin with the old masters whose creations were hammered into sheets of copper and of gold; with the engravers who incised their patterns into metal, stone and wood; and with the Roman slaves who were the motive power behind the

EMBOSSING COINING and STAMPING

colossal wooden mint machines whose stone negatives transformed gold slugs into Caesarian coins.

Today, these same arts are essential in strengthening, decorating, graduating and marking aluminum fabricated articles. The principles are identical, but the means of accomplishment are strictly modern, comprising the direct compression of metal between a punch and a die. Embodied in the direct compression methods most adaptable to sheet aluminum are embossing, coining, semicoining and stamping. These operations are closely allied, and confusion often results when attempts are made to distinguish between them. Sketches shown in Figure 19 have been prepared primarily to aid in a more adept classification, and to describe the peculiarities of each.

Embossing is the production of raised or projected figures or designs in relief on a surface, as at *A* and *B* in Figure 19. At *A* is a section through a stiffening rib and the open die used to produce it. Simple operations

of this kind require relatively light pressures and can hardly be placed in the direct compression group. Such embosses frequently are incorporated in drawing and forming operations. Figure 19B illustrates a more complicated emboss requiring the use of a closed die. Embosses of this kind are definitely within the direct compression group and require comparatively high pressures to produce clear-cut outlines. Note that the thickness of stock is consistent throughout the section—the only factors causing a possible deviation being the mild stresses due to bending and stretching. It may be said that this uniformity of thickness is the identifying characteristic of the emboss.

The use of rubber to supplant the steel female embossing die has proved practical in many instances. The decoration of aluminum foil by passing it between a steel roll having the desired design cut in relief upon its periphery and a smooth rubber-faced contacting roll is but one example of its successful application.

Coining is a method by which the images or characters on a set of molds are impressed into the plane surfaces of a blank or a disk. At *C* in Figure 19 is an example of a coined blank showing how the metal flows between the punch and the die and assumes a contour negative to that of the two faces. In the type of die shown, clearance is allowed for any flash that might occur around the circumference of the blank; when a completely closed die is used, danger may be encountered by over-gauge blanks and the accidental feeding of double blanks. As a precautionary measure, such dies are often mounted on hydropneumatic pressure-equalizing cushions.

Semi-coining is a combination of embossing and coining. It is a mechanical means of doing the work of the hand chaser by causing metal to flow from one part of the emboss to another. The die shown at *D* in Figure 19 is representative of such an operation and is the same in

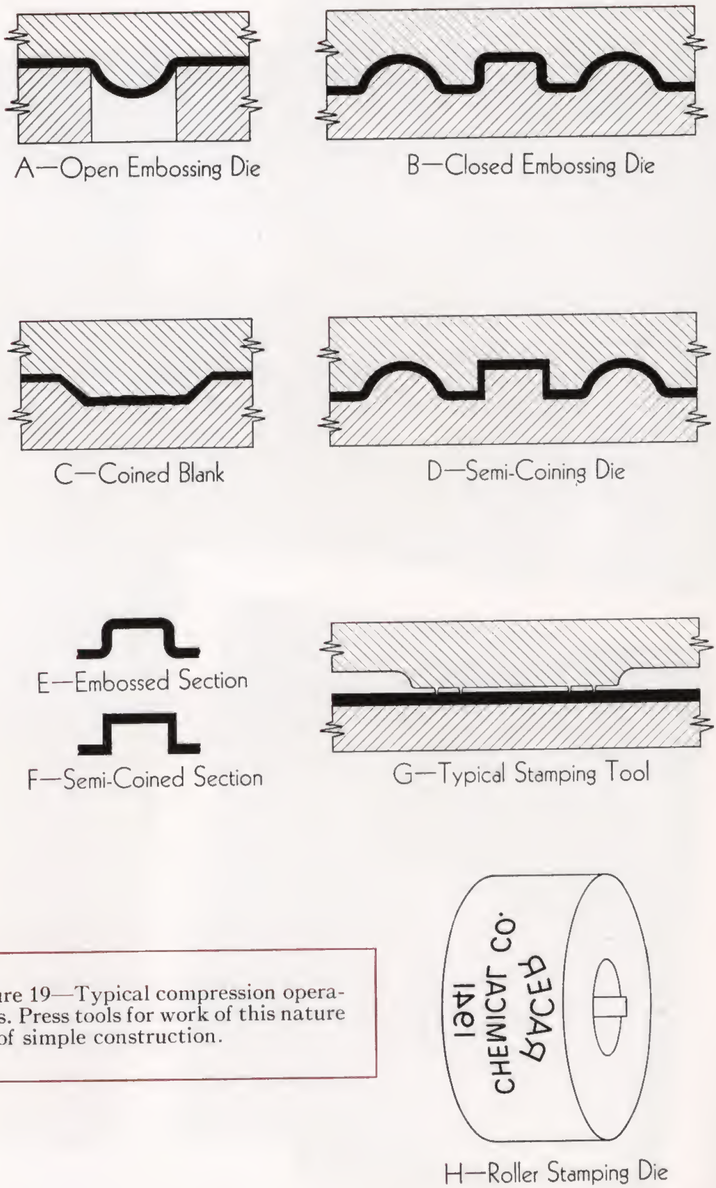


Figure 19—Typical compression operations. Press tools for work of this nature are of simple construction.

Figure 20—This single-action press combines drawing and embossing in one operation.

Figure 21—Stamping the brewer's name on the upper half of aluminum-alloy beer barrel.

all respects as the die at *B* except that the center emboss has a sharp profile. At *E* and *F* are enlarged sections which permit better analysis. It can be readily seen that the vertical side-walls of section *F* are much thinner than those of section *E*. This is the result of a negative clearance between the punch and die, causing them to pinch at this point. The metal thus displaced is of sufficient volume to fill completely the sharp corners of the punch and die and produce the desired profile.

It is important that the tools and blanks for coining and embossing be kept free from foreign substances. The use of oil or other lubricant should be avoided. However, it has been found that in some classes of coining, the use of alcohol or other light lubricant is beneficial.

Stamping refers to the cut lines of letters, figures and decorations resulting from the impact of a stamp having a comparatively sharp projecting outline upon a smooth surface. At *G* in Figure 19 is a cross section of a typical stamping tool. Stamps such as that shown are usually cut to a depth of from 0.020 to 0.040 inch.

SIMPLE PRESS TOOLS USED

The press tools for embossing, coining and stamping are of simple construction. The usual tool consists of a punch and die which are mounted respectively on a punch holder and a die shoe. Except in stamping tools, it is always advisable to use a die set equipped with leader pins, in order to insure proper alignment of the punch and the die. In all coining and embossing tools, the punches and dies serve as forms for producing the desired designs. Aluminum being a comparatively soft metal, the impact of the press will cause it to flow into any minute imperfection in the face of the punch and

die; it is important, therefore, that these parts be kept perfectly smooth and polished. Both the punch and the die should be made of a good grade of tool steel, and hardened so as to better resist the excessive wear to which they are subjected.

In the case of stamping tools, only the punch, on which the desired figure has been cut in relief, is hardened. The die—more correctly defined as the anvil—is smooth and usually made of a mild steel. Horn or single-action presses are often used for light types of work. Frequently the stamping of numerals, trademarks, names and the like is effectively and economically combined with other manufacturing operations, such as drawing, forming and embossing. Stamps for such use are precisely made, and the depth is controlled by the use of shims of suitable thicknesses underneath the stamps.

Roller dies provide a very practical method for stamping. The sketch at *H* in Figure 19 illustrates a roller die used in a marking machine. In flat stamping, the roll is driven over the stationary article and the "marking" is rolled into the surface. Similar stamps are used when the operation of marking cylindrical work is performed in a lathe or similar machine.

In stamping, the depth of penetration should be carefully observed. To prevent distortion and to keep the design from "showing through" on the stamped article, outline or open-faced stamps should be given preference as they do not displace as much metal as the broad-faced stamp.

Special knuckle-joint presses are built for coining and embossing. These machines are of rigid construction and take greater loads in proportion to their weight than any other press. They have short strokes and are designed so that the mechanical advantage of the knuckle joint results in intense pressures during the last portion of the stroke. Precision adjustment of the tool space is provided.

EFFECT OF MATERIAL USED

Controlling factors in the coining and embossing of aluminum, so far as the metal is concerned, are its malleability and its ductility. The former is its characteristic to yield to compressive and impact forces, and the latter is a qualitative term referring to elongation produced by tension.

Within certain limitations, when a deforming force is removed from a piece of aluminum it will regain its former shape. When this limit is passed, the metal takes a permanent set or only partially recovers. If, however, the deforming force is increased so as to produce a progressive deformation, then fracture will eventually result. It is the range, therefore, between the limit of elasticity, which must be passed and the ultimate strength which must not be exceeded, that constitutes the field for embossing.

Aluminum sheet is available in a variety of degrees of hardness from "dead soft" to "hard." Since temper affects its resiliency, or ability to absorb shock without permanent deformation, it is only logical that the "dead-soft" or intermediate tempers, such as "¼*H*" and "½*H*," or "*W*" in the case of heat-treated alloys, are preferable for embossing. A good rule to follow is to select a grade and temper with as high elongation and as low a ratio of yield strength to tensile strength as possible, consistent with the properties required by service conditions.

For decorative purposes, the stamped or embossed piece can be given a variety of finishes to enhance its appearance. The finish may also contribute other salient characteristics, such as improved or lowered reflectivity and resistance to corrosion and abrasion.

SALES OFFICES

AKRON, OHIO	611 Akron Savings and Loan Bldg.
ALBANY, N. Y.	90 State St.
ATLANTA, GA.	1818 Rhodes-Haverty Bldg.
BOSTON, MASS.	20 Providence St., Park Square
BUFFALO, N. Y.	1880 Elmwood Ave.
CHARLOTTE, N. C.	619 Johnston Bldg.
CHICAGO, ILL.	520 North Michigan Ave.
CINCINNATI, OHIO	16th Floor, Times-Star Bldg.
CLEVELAND, OHIO	2210 Harvard Ave.
DALLAS, TEXAS	2102 Bryan St.
DAVENPORT, IOWA	918 Kahl Bldg.
DAYTON, OHIO	301 Harries Bldg.
DENVER, COLO.	634 U. S. National Bank Bldg.
DETROIT, MICH.	3311 Dunn Rd.
FAIRFIELD, CONN.	Boston Post Rd.
HARTFORD, CONN.	Capitol Bldg., 410 Asylum St.
INDIANAPOLIS, IND.	1008 Merchants Bank Bldg.
KANSAS CITY, MO.	2306 Power & Light Bldg.
LOS ANGELES, CALIF.	5151 Magnolia Ave.
MILWAUKEE, WIS.	735 North Water St.
MINNEAPOLIS, MINN.	1060 Northwestern Bank Bldg.
NEWARK, N. J.	Newark & Essex Bldg.
NEW ORLEANS, LA.	1915 American Bank Bldg.
NEW YORK, N. Y.	230 Park Ave.
PHILADELPHIA, PA.	123 South Broad St.
PITTSBURGH, PA.	Gulf Bldg.
RICHMOND, VA.	213 Builders Exchange
ST. LOUIS, MO.	1002 Continental Bldg.
SAN FRANCISCO, CALIF.	709 Rialto Bldg.
SEATTLE, WASH.	1005 White Bldg.
TOLEDO, OHIO	1804 Ohio Bank Bldg.
WASHINGTON, D. C.	605 Southern Bldg.

The word "Alcoa" and the adjacent design are registered trademarks applied to the products of Aluminum Company of America, whose technical staff exercises the most rigid control over every process in the production of Alcoa Aluminum . . . from the mining of bauxite ore to the production of uniform and high quality aluminum and aluminum alloys, in every commercial form.

IBM MS 9755

TO BORROWER: DO NOT REMOVE THIS CARD FROM POCKET. A CHARGE OF $1.00 WILL BE MADE IF CARD IS MISSING OR MUTILATED WHEN BOOK IS RETURNED

AMERICA FORMING

ALCOA

A.C.

ALUMINUM

O.A.